724

170
5-2-74

MLM-2134

Sta. Plus Special Distr

MLM-2134

Advanced Heat Source Concepts

J. E. Selle

April 10, 1974

MASTER

AEC Research and Development Report

MOUND LABORATORY
Miamisburg, Ohio
operated by

Monsanto

MONSANTO RESEARCH CORPORATION
a subsidiary of Monsanto Company
for the

U. S. ATOMIC ENERGY COMMISSION

U. S. Government Contract No. AT-33-1-GEN-53

DISCLAIMER

MLM-2134
TID-4500
UC-23

Advanced Heat Source Concepts

J. E. Selle

Issued: April 10, 1974

NOTICE

PRINTED IN THE UNITED STATES OF AMERICA
Available from
National Technical Information Service
U S Department of Commerce
5285 Port Royal Road
Springfield Virginia 22151
Price Printed Copy $4 00, Microfiche $1 45

MONSANTO RESEARCH CORPORATION
A Subsidiary of Monsanto Company

MOUND LABORATORY
Miamisburg, Ohio 45342

operated for

UNITED STATES ATOMIC ENERGY COMMISSION
U S Government Contract No AT-33-1-GEN-53

MASTER 1

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ABSTRACT

Recent trends in heat source programs indicate the feasibility of a modular approach to heat source design. In this approach, modules, comprised of a number of individually encapsulated units or capsulettes, are stacked together to form one heat source. Each capsulette can independently survive impact and post-impact containment. Such heat sources are useful for electrical power generation in space.

The use of radioisotopic heat sources in the Apollo missions (SNAP-27), the Nimbus weather satellite (SNAP-19), and the Jupiter fly-by mission (Pioneer) has proven the practicality of generating electrical power with these sources in space applications. In addition, other heat sources have demonstrated the potential of using nuclear energy in space. These include the Pioneer Radioisotopic Heater Unit (PRHU) and the Apollo Lunar Radioisotopic Heater (ALRH). Medical uses of radioisotopic heat sources are also becoming increasingly important.

Heat sources for electrical power generation in space are the subject of this paper.* At the present time there are five types of such heat sources now in use in radioisotopic thermoelectric generators (RTG). These are SNAP-3, SNAP-9, SNAP-19B, SNAP-27, and Pioneer/TRANSIT/Viking. Each of these heat sources was tailor-made for a specific program and hence is completely different from the others. The basic characteristics of each are summarized in Table 1. The fact that each of these sources was produced under a separate program means that very little of the technology developed for prior programs was utilized. As a result, these programs have been very expensive. If radioisotopic heat sources are to survive in competition with other forms of power generation, economies in the overall cost per unit are mandatory, and future heat source designs must consider these economies.

At the minimum, specific attention must be given, in any heat source design, to the following:

1. Safety
2. Material Compatibility
3. Cost
4. Weight
5. Specific Thermal Power
6. Helium Management
7. Operating Temperature
8. Fabricability
9. Operating Environment

In view of environmental considerations and political implications, and in spite of their importance, safety must be considered to be of prime importance. Specifically, any safety analysis must consider:

1. Launch Pad Abort
2. Launch Failure
3. Re-Entry

*Invited paper presented at the 18th Annual American Nuclear Society Meeting, Las Vegas, Nevada, June 18-22, 1972.

Table 1

CHARACTERISTICS OF HEAT SOURCES IN ACTIVE USE FOR RTG'S IN SPACE

Heat Source	Fuel Form	Liner Material	Strength Member Material	Outer Container Material	Watts (Thermal)
SNAP-3-2	Pu-238 Metal	Tantalum	---	Haynes-25	52.5
SNAP-9A	Pu-238 Metal	Tantalum	---	Haynes-25	87.5
SNAP-19B	Pu-238 Micro-sphere	Haynes-25	---	---	570
SNAP-27	$^{238}PuO_2$ Micro-spheres (annular configuration)	Haynes-25	---	Haynes-25	1480
Pioneer/ TRANSIT/ Viking	PuO_2-Mo Cermet Discs	Ta-10W	T-111	Pt-20Rh	640/825/675

4. Impact
5. Post-Impact Containment
6. Fuel Containment
7. Working Environment of the Heat Source

Unfortunately, the design required to satisfy any particular requirement may be a poor design for one of the others. For example, a material that is good for fuel containment may be unacceptable for impact resistance; or a material with adequate impact resistance may be poor for post-impact containment. Therefore, optimization of the system is necessary, and proper trade-offs must be made. These trade-offs lead to extrapolations and their attendant uncertainties.

With safety as the prime consideration in heat source design, an increased burden is placed on the cost of a system. Since safety considerations are expensive in most cases, it becomes increasingly important to realize economies in other facets of the programs. A look at the more recent events in radioisotopic heat source programs suggests one system for cost reduction. The TRANSIT and Pioneer heat sources both utilize the same basic design, and the Viking heat source will continue this trend with some modifications, the primary difference among these heat sources being their lengths. The effect of their similarities is a considerable savings in fabrication and testing costs.

However, these capsules suffer from at least one serious drawback, that of post-impact containment. Regardless of the materials of construction, the probability of post-impact containment decreases as the temperature increases. The post-impact ground temperature for both the TRANSIT and Pioneer heat sources is about 600°C. Decreasing this temperature would result in increased probability of containment, and hence in increased safety and protection of the environment.

The most obvious method of decreasing the post-impact temperature is to use smaller units. This, then, points to a heat source made from a number of smaller units or capsulettes which could separate either before reentry or after impact, resulting in lower ground temperatures. If each of these self-contained units or capsulettes could be made to survive impact without rupture, the decreased temperature would add an extra measure of safety.

To a certain extent the TRANSIT and Pioneer capsules are already modular in that the fuel discs are in effect a capsulette. The required number of discs are stacked to obtain the necessary wattage. The primary drawback is that the fuel discs are not individually encapsulated and, therefore, would not survive an impact without release of activity. It would seem that by a slight extension of current trends, a more satisfactory heat source for future use could be derived.

A heat source based on the modular concept is shown schematically in Figure 1. This is meant to be conceptual only; it is by no means a specific design. (Other designs or configurations have been studied, and each has its own advantages and disadvantages.) In this configuration, individual encapsulations are stacked together into a module which in itself is enclosed in a separate container. One conceptual design of a capsulette is shown in Figure 2. Simulant compacts of this design have been produced.[1] Any number of these modules can then be arranged into any given configuration to form a heat source. The size and shape of the

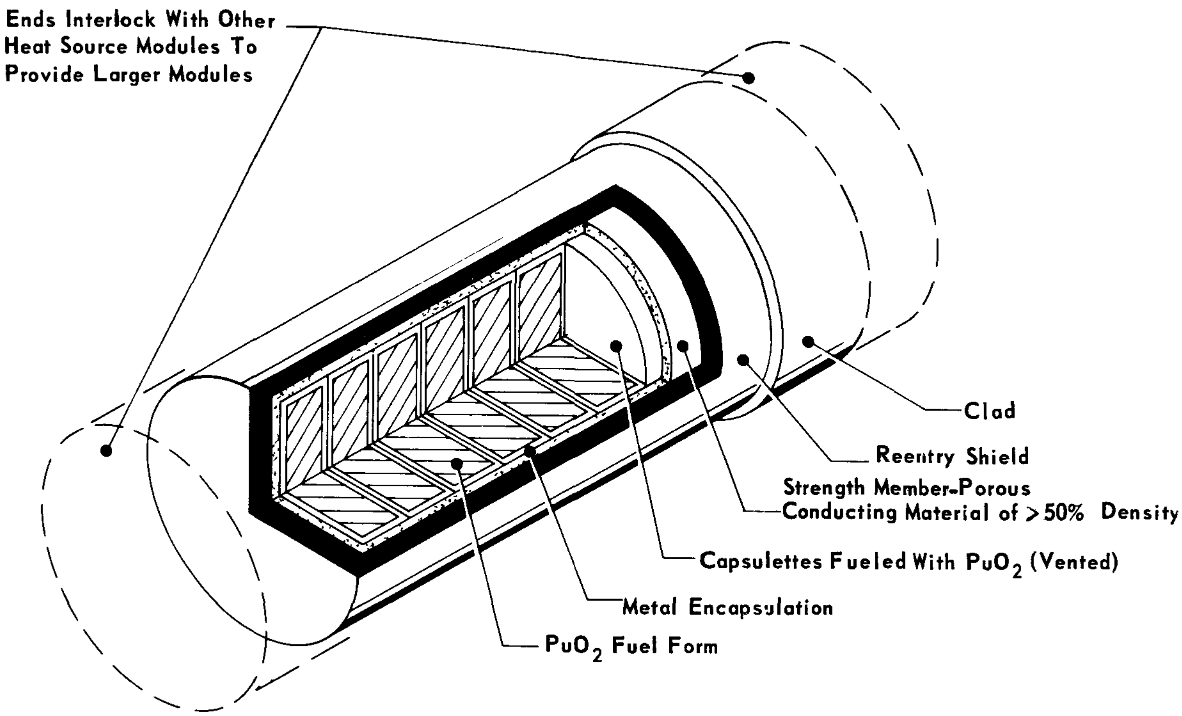

FIGURE 1 - Conceptual design of modular type heat source unit.

encapsulations would be a function of several considerations such as: safety requirements (at re-entry, impact, etc.); availability of materials; fabrication cost; and user requirements (specific generator design).

The present Multihundred Watt (MHW) Program approaches this concept. However, the MHW heat source is a tailored heat source which is designed for a specific mission. Its adaptability to other programs, or its use as a "universal" heat source is somewhat questionable. Each sphere (capsulette) is about 100 watts of fuel, which is somewhat large for present needs.

Among the advantages of a modular heat source are:

1. Adaptability to programmatic changes

2. Lower source term per capsulette

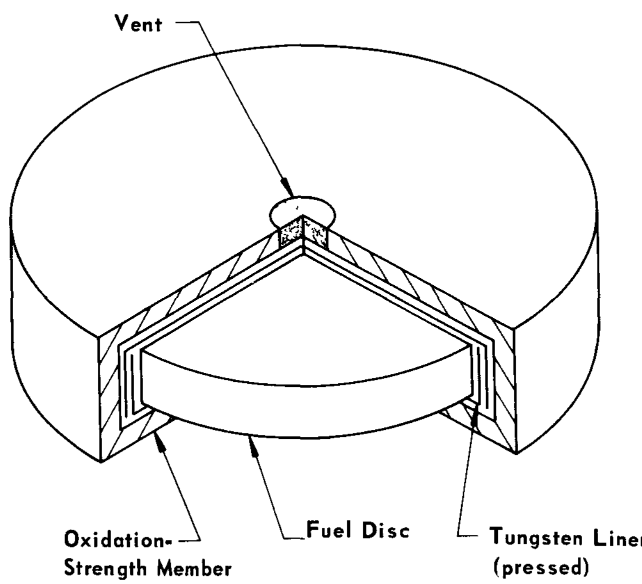

FIGURE 2 - Preliminary conceptual design of capsulette.

3. Lower overall cost per watt
4. Ease in handling and storage
5. Improved post-impact containment
6. Shorter program turn-around time
7. Increased flexibility of fabrication schedules
8. Modularity of computer programs
9. Less expensive testing
10. Feasibility of full-scale proof testing of capsulettes.

From time to time, improvements or changes may be made in a heat source for one reason or another. In general, these changes are either process changes or material changes, both of which are summarized in Table 2. Material changes often require more retesting and qualification than process variables. Ideally, this testing should be done on full-sized units. With the present system, testing a full-sized heat source involves large quantities of fuel and enormous costs. Testing of the small capsulettes is more feasible from both an economics and a handling point of view. Sequential testing and postmortem analyses are more practical with the smaller units than with larger units. In addition, material systems testing can be done on the capsulettes and the results can be related to real life. Present methods use simulated or scaled-down testing procedures with subsequent extrapolations and other associated ambiguities.

Future heat sources will probably utilize materials other than those listed in Table 1. This is due in part to the increasing of heat source operating temperatures and in part to the marginal acceptability of present materials. Hopefully, one or both of the newer alloys under consideration (i.e., Hafnalloy, developed by TRW or PT-3010, developed by ORNL) will prove useful in the future.

Table 2

SUMMARY OF VARIABLES IN HEAT SOURCE FABRICATION

Process Variables	Material Variables
Size of unit	Fuel form
Shape of unit	Addition or deletion of material
Fabrication procedures (hardware)	
Assembly techniques	
Fuel fabrication techniques	

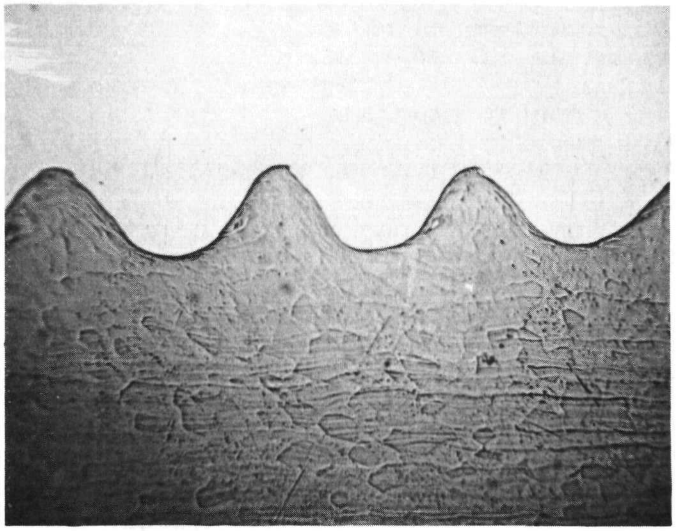

FIGURE 3 - Photomicrograph of the interface between Pt-20 Rh (top) explosion-bonded to T-111 (bottom).

Changes are also probable in fabrication and assembly techniques. One interesting possibility is the use of explosive-bonded materials, particularly for post-impact oxidation resistance. A photomicrograph of the interface between a sheet of Pt-20 Rh alloy explosion-bonded to T-111 is shown in Figure 3. The intimate contact between the two materials coupled with the serrated interface renders this material more resistant to peeling or shearing during impact.

SUMMARY

Changes in safety philosophy coupled with the increasing of operational temperatures have been largely responsible for the evolution of heat source designs to their present state. Recent trends in heat source programs indicate the feasibility of a modular approach to heat source design in order to reduce costs. A modular type of heat source is made up of a stack of individually encapsulated units or capsulettes, each capable of surviving impact and post-impact containment. Increased safety and lower testing costs are expected.

REFERENCE

1. W. D. Pardieck, Encapsulation of ThO_2 in Molybdenum Liners Via Hot Pressing, MLM-2076 (Oct. 11, 1973), 12 pp.